Proc. NIPR Symp. Upper Atmos. Phys., 1, 192–198, 1988

SATELLITE OBSERVATION OF MEDIUM-SCALE TRAVELING IONOSPHERIC DISTURBANCES OVER SYOWA STATION

Tadahiko OGAWA, Kiyoshi IGARASHI, Kazuhiro AIKYO and Hideo MAENO

Radio Research Laboratory, 2-1, Nukui-Kitamachi 4-chome, Koganei-shi, Tokyo 184

Abstract: From March 9, 1985 to January 11, 1986, 428 medium-scale traveling ionospheric disturbances (TID's) were detected at Syowa Station, Antarctica, by means of differential-Doppler measurements with the 150 and 400 MHz beacon waves from six NNSS satellites. It is found from statistical analysis that (1) the medium-scale TID's in the polar regions appear quite often during geomagnetically quiet and moderately disturbed conditions and their occurrence seems not to increase with increasing geomagnetic activity, (2) they attain the maximum activity in winter and the minimum in summer, (3) diurnal variation shows the maximum occurrence around 1400–1600 LT with a second maximum around midnight, and (4) most of the medium-scale TID's propagate from south toward the equator. These findings are compared with observations made at midlatitude to find a fairly good consistency between both results. It is pointed out that the gravity waves excited in the mesosphere rather than in the auroral ionosphere play an important role in producing most of the observed medium-scale TID's.

1. Introduction

Traveling ionospheric disturbances (TID's) which are wave-like fluctuations of the ionospheric electron density are induced by internal atmospheric gravity waves in the neutral atmosphere (YEH and LIU, 1974). There are two classes of TID's: large-scale TID's characterized by higher speeds (400–1000 m/s) and longer periods (0.5–3 h) with wavelengths greater than 1000 km, and medium-scale TID's characterized by lower speeds (100–250 m/s) and shorter periods (15 min–1 h) with wavelengths of several hundred km. The medium-scale TID's appear more frequently than the large-scale ones which can be related to specific geophysical events like auroral substorms (HUNSUCKER, 1982). FRANCIS (1975) pointed out that although auroral sources of the medium-scale TID's have attracted the greatest attention, the existence of other sources is also possible. This indicates that the sources of the medium-scale TID's are not unique but diverse.

TID's have been observed by various methods including vertical-soundings, incoherent scatter radars, HF Doppler measurements, total electron content measurements by Faraday rotation, and *in situ* measurements of electron density. In this report, we describe some statistical results from medium-scale TID observations in the southern polar region carried out at Syowa Station (69.0°S, 39.6°E), Antarctica, during March 1985 to January 1986. TID's were detected on the differential-Doppler records of changes in total electron content during the receiving of the 150 and 400 MHz radio beacons from six NNSS (Navy Navigation Satellite System) satellites

(EVANS *et al.*, 1983).

One of our important findings is that the seasonal medium-scale TID activity may well reflect the seasonal gravity wave activity in the Antarctic middle atmosphere.

2. Observations

The polar-orbiting NNSS satellites have an altitude of about 1000 km. Six satellites were in operation during the experimental period from March 9, 1985 to January 11, 1986. There were one or two (occasionally, three) passes every hour, and for each pass the beacon waves at 150 and 400 MHz were received for ten minutes on the average from horizon to horizon as the satellite traveled from north to south or *vice versa*. In total, differential-Doppler records of more than 10000 passes were obtained for almost all local times and seasons, under various geomagnetic activity conditions.

As a beacon receiver, we used a modified commercial NNSS satellite receiver for navigation purpose. The 400 MHz beacon signal received by a whip-type antenna was used to lock the phase of an oscillator in the phase-locked receiver. The output frequency (f_{400}) of this oscillator was multiplied by 3/8 to be used as a reference frequency for the 150 MHz beacon signal (f_{150}) in a phase detector. The output of this phase detector, $\Delta f(=f_{150}-3f_{400}/8)$, called the differential-Doppler signal, is proportional to the rate of change of the phase path length through the ionosphere.

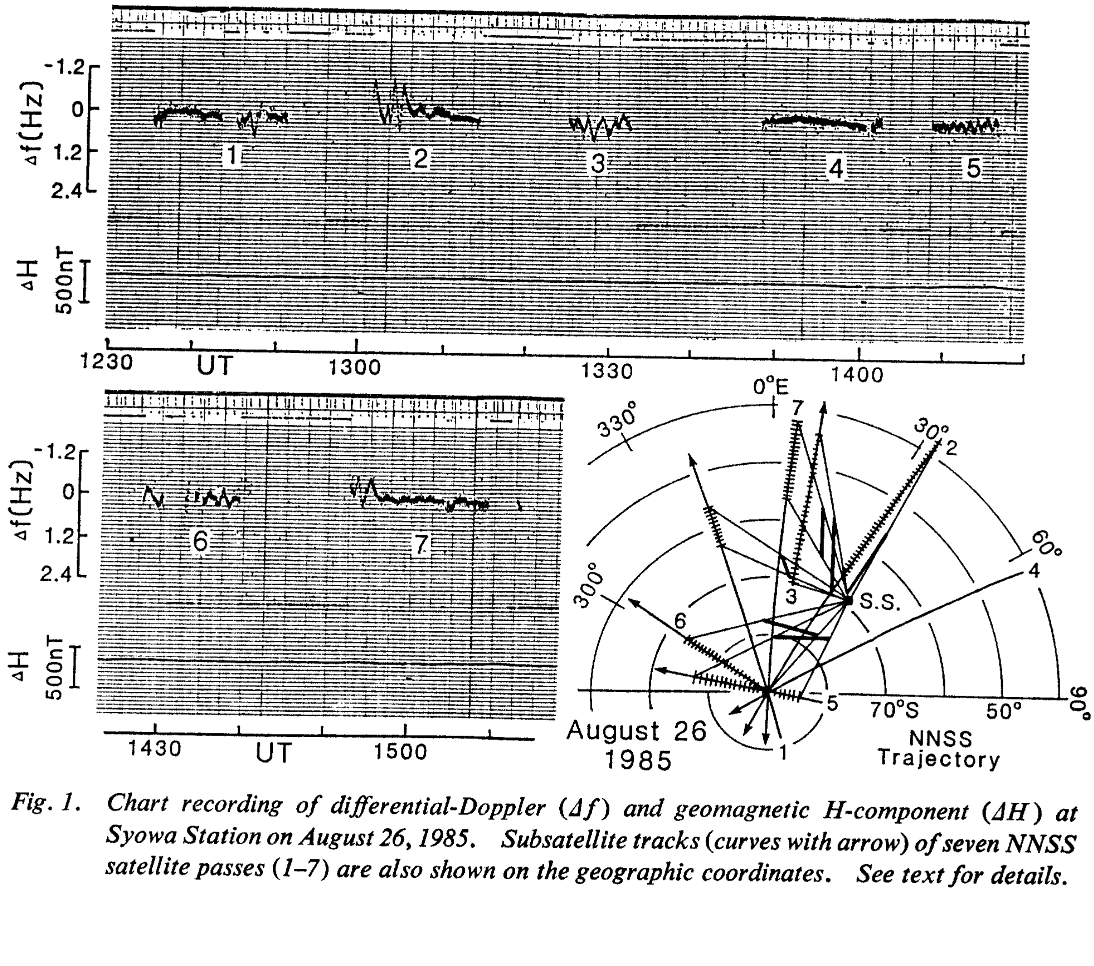

Fig. 1. Chart recording of differential-Doppler (Δf) and geomagnetic H-component (ΔH) at Syowa Station on August 26, 1985. Subsatellite tracks (curves with arrow) of seven NNSS satellite passes (1–7) are also shown on the geographic coordinates. See text for details.

Since Δf includes information on total electron content (LEITINGER *et al.*, 1984), oscillatory features of the ionosphere are manifested as oscillations on Δf records.

Figure 1 shows an example of the differential-Doppler (Δf) record obtained on August 26, 1985. There were seven successive satellite passes during 1230–1510 UT (1530–1810 LT) when the geomagnetic H-component (ΔH) was very quiet and showed no substorm activity. Except the pass number 4, oscillation of Δf is clearly seen on each pass. It is believed that such oscillations are due to TID's (EVANS *et al.*, 1983). Seven subsatellite tracks are also shown on the geographic coordinates in Fig. 1 where the satellite moved along the curve with arrow, and the tick-marks on the track indicate the interval of Δf oscillations. Since TID's are phenomena mainly at the F-region height, we also indicate by heavy solid lines in Fig. 1 the 300 km subionospheric points (defined as the intersection points of the radio path with a shell at 300 km altitude) during the intervals of the oscillation occurrence on each pass.

Predominant oscillation periods of 1–2 min seen in Fig. 1 can be converted into spatial wavelengths of 300–600 km in the F-region, by taking into account the high traveling velocity of satellite ($\sim$8 km/s) and far lower velocities of TID's ($\lesssim$1 km/s). Therefore, these oscillations can be categorized as medium-scale TID's. It is difficult to recognize the oscillations with periods longer than several minutes (large-scale TID's) on the chart records because of short receiving times (<15 min) of the satellite signals.

3. Statistical Results and Discussion

During a 10-month period, there were 428 passes, in which Δf oscillation (medium-scale TID) lasted, at least, two cycles on the chart recording. Number of TID's (B) is plotted in the bottom of Fig. 2 as a function of 3-h K-index at Syowa Station, along with the total occurrence frequency (A) of each K-index value. B/A showing the probability of the TID occurrence at a given K-index is plotted in the top of Fig. 2. It is clear from Fig. 2 that the occurrence probability decreases monotonically with increasing K-index. One important observational fact must be borne in mind in understanding this result: with increasing geomagnetic activity (K-index), Δf's tend to be more scattered because the 150 and 400 MHz radio waves from the NNSS satellites are subject to stronger scintillations due to well-developed small-scale ionospheric irregularities, resulting in frequent difficulty of identifying oscillatory structures on the chart records even if TID's take place actually. Anyway, one conclusion from Fig. 2 is that the medium-scale TID's appear even under geomagnetically quiet (K=0, 1 and 2) and moderately disturbed (K=3 and 4) conditions, thus suggesting a role of atmospheric gravity waves produced by some mechanisms other than auroral electrojet activities like Joule heating and/or Lorentz force (HUNSUCKER, 1982). EVANS *et al.* (1983) have found from NNSS observations at midlatitude (Millstone Hill; 42.6°N) that there seems no increase in TID occurrence during geomagnetically disturbed times. Their result is consistent with our observations.

Figure 3 shows the occurrence number of TID's *versus* month (histogram) together with the average occurrence number per day. It is clear that the TID activity is highest in August (in southern winter) and lowest in January (in summer). This finding is also

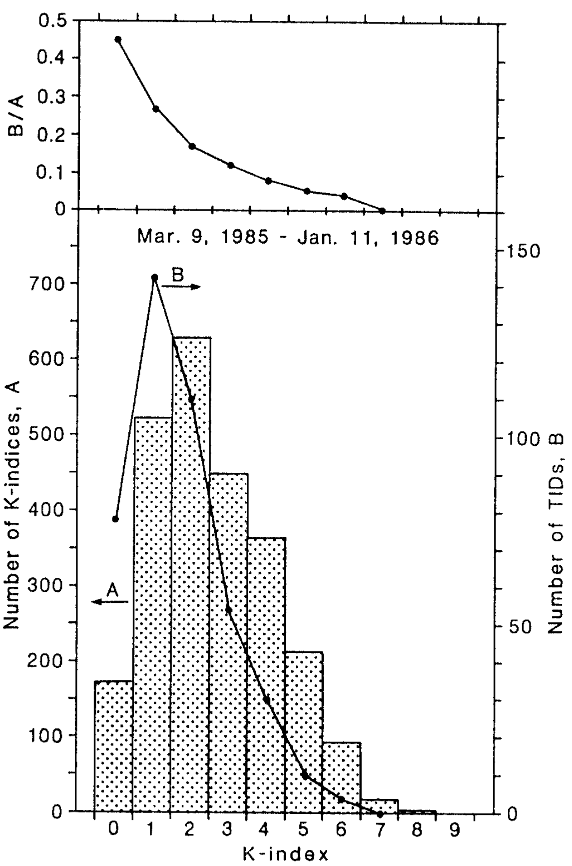

Fig. 2. Occurrence number of medium-scale TID's (B) and histogram of occurrence number of K-indices (A) versus local K-index (bottom diagram), and B/A showing the occurrence probability for a given K-index (top diagram).

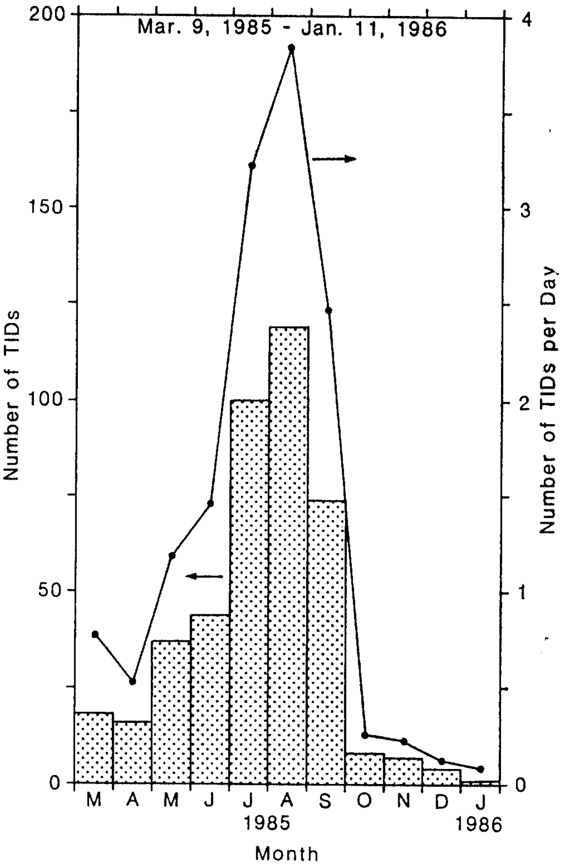

Fig. 3. Seasonal variations in the occurrence of medium-scale TID's (histogram) and their average occurrence per day (solid line).

partly consistent with that by EVANS *et al.* (1983) who pointed out that the seasonal variation is less clear but the occurrence seems to be increased in winter and the equinoxes and reduced in summer. They attributed this seasonal variation to a dependence of the detectability on total electron content. That is, the detectability of an acoustic gravity wave depends on the ambient ionization density (f_oF2), and it may not be detected by the present technique when the ambient ionization density is below some threshold value.

HIROTA (1984) has found from meteorological rocket data that the gravity wave activity in the middle atmosphere shows a notable annual cycle in higher latitudes with the maximum in wintertime while it shows a semiannual cycle in lower latitudes with the maximum around the equinoxes. This finding can give an explanation to our result shown in Fig. 3. That is, our seasonal TID activity can be well explained by the seasonal gravity wave activity in the high latitude middle atmosphere. This means that the gravity waves in the Antarctic middle atmosphere can go up to the *F*-region ionosphere without severe attenuation. We note here that the seasonal variation found by EVANS *et al.* (1983) can be partly explained by HIROTA's con-

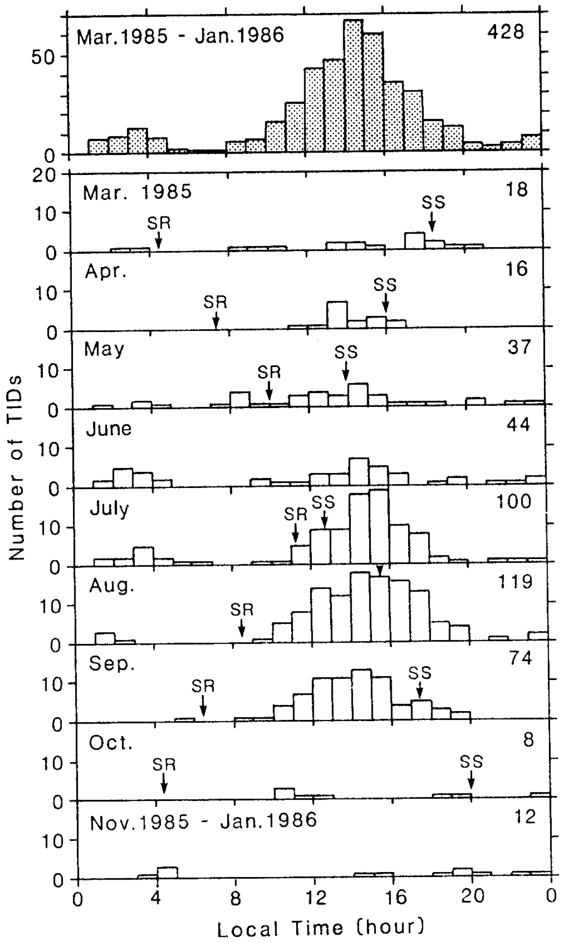

Fig. 4. Diurnal variations in the occurrence of medium-scale TID's in each month (lower panel) and for ten months (upper panel). Number of TID's in each month is also indicated. SR and SS denote mean local sunrise and sunset hours, respectively (note no sunshine in June).

clusion, though they attributed the seasonal variation to the detectability of gravity waves.

Figure 4 shows the diurnal occurrence of the medium-scale TID's in each month (lower panel) and for full experimental period (upper panel). In the upper panel, there are two maxima: one around midnight and the other in the afternoon hours. The former increase is partly attributed to auroral electrojet activities since Syowa Station is usually located under the auroral oval during disturbed conditions, while the latter increase cannot be due only to electroject activities since Syowa Station is usually far from the oval so that we must look for other candidates. The daytime increase was found by EVANS *et al.* (1983) who also attributed this increase to the detectability of TID's. This detectability also may be partly true for our case though we have no data (f_oF2) supporting their idea. As can be observed in Fig. 4, however, we detected the maximum increase after the sunset rather in daytime hours in May, June and July.

It is known that the medium-scale TID has a negative wave front tilt in the propagation direction of about $-45°$ (DAVIES and JONES, 1971). This tilt can be explained by an acoustic gravity wave coming from the lower atmosphere. Relying on this feature, we can expect that TID is best detected when the elevation angle of radio path from NNSS to the observer coincides with the wave front tilt (EVANS *et al.*, 1983).

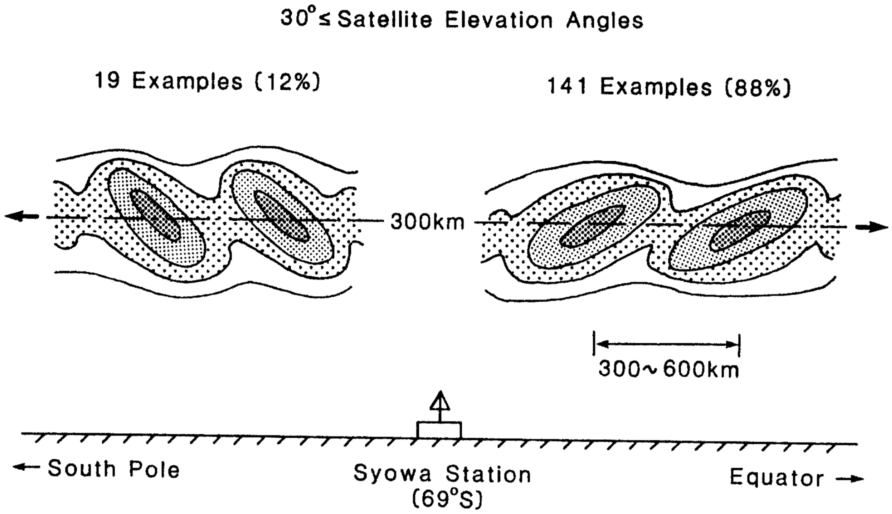

Fig. 5. Schematic illustration of medium-scale TID's propagating equatorward (northward) and poleward (southward).

Actually, the oscillations on the passes 2 and 7 in Fig. 1 were detected around the beginning of each south-bound pass, namely, to the north of Syowa Station. These oscillations can be understood as caused by the northward-(equatorward-)propagating gravity waves.

160 medium-scale TID observations with the maximum satellite elevation angles greater than 30° were extracted to determine whether they were detected to the north or south of Syowa Station. The result is schematically illustrated in Fig. 5; the TID's were detected to the north (equatorward) for 88% of the observations and to the south (poleward) for 12%, thereby suggesting that most of the TID's were propagating equatorward from south. This conclusion is also consistent with the result by EVANS *et al.* (1983) who pointed out that in winter and the equinoxes the majority of TID's were seen to the south (equatorward) of Millstone Hill.

4. Concluding Remarks

Medium-scale TID observations at Syowa Station, Antarctica, by means of differential-Doppler of the NNSS satellites have been described. We find that (1) the medium-scale TID's in the polar regions appear quite often even under geomagnetically quiet and moderately disturbed conditions and their occurrence seems not to increase with increasing local *K*-index, (2) they attain the maximum activity in August (wintertime) and the minimum around January (summertime), a result being consistent with the seasonal variation of the gravity wave activity in the high latitude mesosphere, (3) the diurnal variation of the TID activity shows the maximum occurrence at 1400–1600 LT, which may result partly from easier detectability of TID's during daytime hours, and a second maximum around midnight due to auroral activities, and (4) most of the TID's were detected to the north of Syowa Station, thereby suggesting that they were propagating equatorward from south to north.

It is important to note here that the seasonal and diurnal TID activity detected at ionospheric heights may not always represent the gravity wave activity in the mesosphere. We must consider the filtering and thermospheric wind effects on up-going waves and also the detectability of electron density waves in the ionosphere by our technique. At present, it is very difficult to estimate these effects on our statistical results. It may be, however, somewhat surprising that our results are nearly consistent with those by EVANS *et al.* (1983) at midlatitude. This may confirm that the medium-scale TID's originated in the polar regions can travel easily toward the equator (FRANCIS, 1974).

Medium-scale TID's in high- and mid-latitudes have been often investigated in relation to auroral activities like perturbations in the auroral electrojet (Lorentz force and Joule heating), auroral particle precipitation and supersonic movement of auroral arcs (*e.g.*, FRANCIS, 1974; HUNSUCKER, 1982). Our results, however, suggest that the gravity waves excited in the mesosphere rather than in the auroral ionosphere play an important role in producing most of the observed medium-scale TID's (FRANCIS, 1975).

Acknowledgments

We would like to thank Mr. Y. KURATANI for his help in this research project. We also thank the members of the Japanese 1985–1986 wintering party headed by Prof. H. FUKUNISHI for their kind support to the experiment.

References

DAVIES, K. and JONES, J. E. (1971): Three-dimensional observations of traveling ionospheric disturbances. J. Atmos. Terr. Phys., **33**, 39–46.

EVANS, J. V., HOLT, J. M. and WAND, R. H. (1983): A differential-Doppler study of traveling ionospheric disturbances from Millstone Hill. Radio Sci., **18**, 435–451.

FRANCIS, S. H. (1974): A theory of medium-scale traveling ionospheric disturbances. J. Geophys. Res., **79**, 5245–5260.

FRANCIS, S. H. (1975): Global propagation of atmospheric gravity waves; A review. J. Atmos. Terr. Phys., **37**, 1011–1054.

HIROTA, I. (1984): Climatology of gravity waves in the middle atmosphere. J. Atmos. Terr. Phys., **46**, 767–773.

HUNSUCKER, R. D. (1982): Atmospheric gravity waves generated in the high-latitude ionosphere; A review. Rev. Geophys. Space Phys., **20**, 293–315.

LEITINGER, R., HARTMANN, G. K., LOHMAR, F.-J. and PUTZ, E. (1984): Electron content measurements with geodetic Doppler receivers. Radio. Sci., **19**, 789–797.

YEH, K. C. and LIU, C. H. (1974): Acoustic-gravity waves in the upper atmosphere. Rev. Geophys. Space Phys., **12**, 193–216.

(Received May 25, 1987; Revised manuscript received July 27, 1987)